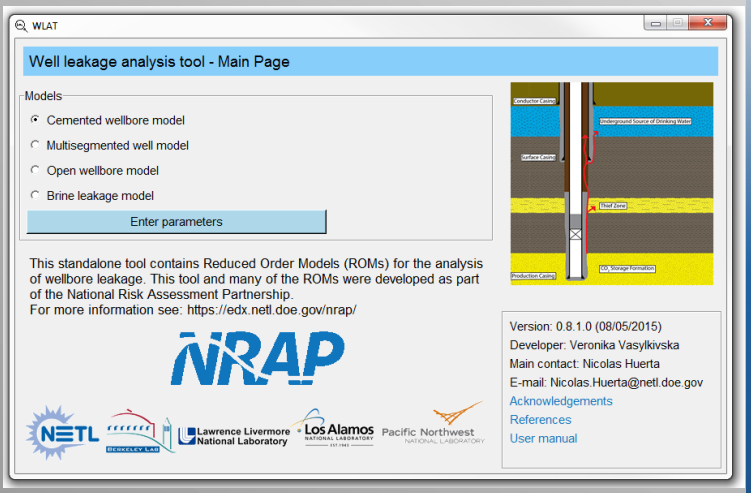


NRAP Risk Assessment Tool Webinar Series

Webinar 4

Well Leakage Analysis Tool (WLAT): A Collection of Stand-alone Well Leakage Reduced Order Models

Monday November 02, 2015

Presenter: **Nicolas J. Huerta**
Predictive Geosciences Division, NETL

NRAP National Risk Assessment Partnership

U.S. DEPARTMENT OF ENERGY

Webinar Outline

I. NRAP overview
II. WLAT overview and background
III. Input needed
IV. Software walkthrough
V. Example use cases
VI. QA/QC and future developments
VII. Questions and Open Discussion

Please Use Land-Lines for Audio; Please Mute Your Phone.

I. National Risk Assessment Partnership (NRAP)

NRAP leverages DOE's capabilities to help quantify uncertainties and risks necessary to remove barriers to full-scale CO_2 storage deployment.

Objective: ***Building toolsets and improving the science base to address key questions about potential impacts related to release of CO_2 or brine from the storage reservoir, and potential ground-motion impacts due to injection of CO_2***

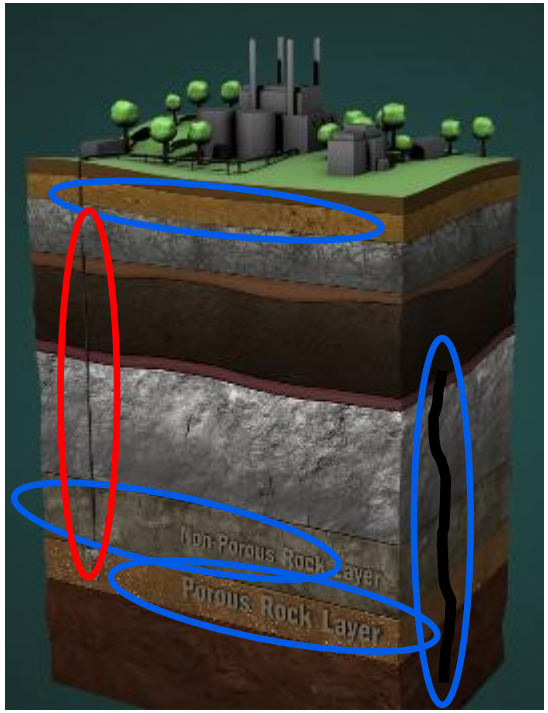
Technical Team

NETL

Berkeley Lab

Los Alamos National Laboratory EST.1943

Pacific Northwest National Laboratory



Stakeholder Group

AEP American Electric Power

Blue Source

bp

EPA United States Environmental Protection Agency

ExxonMobil

ieaghg

IEc

MIT

NRDC

Schlumberger

Southern States Energy Board

Stanford University

Texas Railroad Commission

USGS

The University of Utah

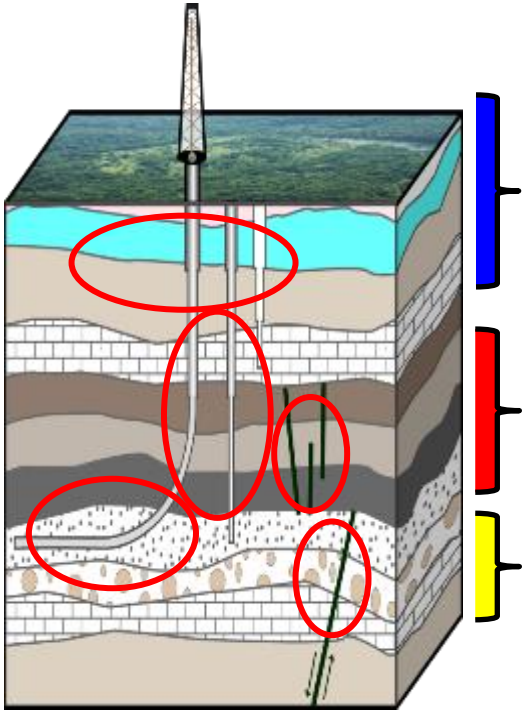
Wade, LLC

Whiting

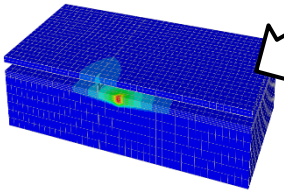
Zurich Because change happens

NRAP's approach to quantifying performance relies on reduced-order models to probe uncertainty in the system

A. Divide system into discrete components



B. Develop detailed component models that are validated against lab/field data

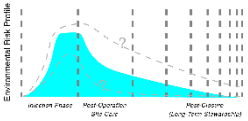


Energy Data Exchange (EDX)

Data

IAM

NRAP Integrated Assessment (System) Models



Potential Receptors or Impacted Media

Release and Transport

Storage Reservoir

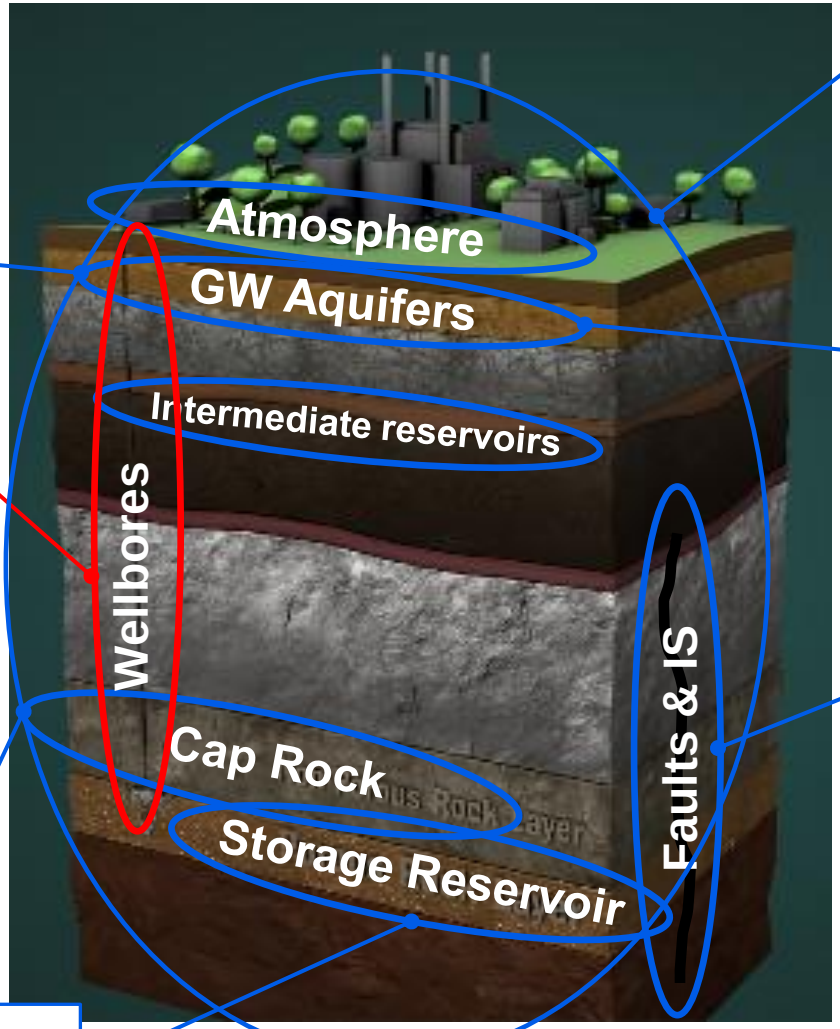
C. Develop reduced-order models (ROMs) that rapidly reproduce component model predictions

D. Link ROMs via integrated assessment models (IAMs) to predict system performance & risk; calibrate using lab/field data from NRAP and other sources

E. Develop strategic monitoring protocols that allow verification of predicted system performance

NRAP Tools

Now available for beta testing



NRAP-IAM-CS

Design for Risk Evaluation and Monitoring

Aquifer Impact Model

Wellbore Leakage Analysis Tool

Short Term Seismic Forecasting

Natural Seal ROM

Reservoir Evaluation and Visualization

www.edx.netl.doe.gov/nrap → *TOOL BETA TESTING link*

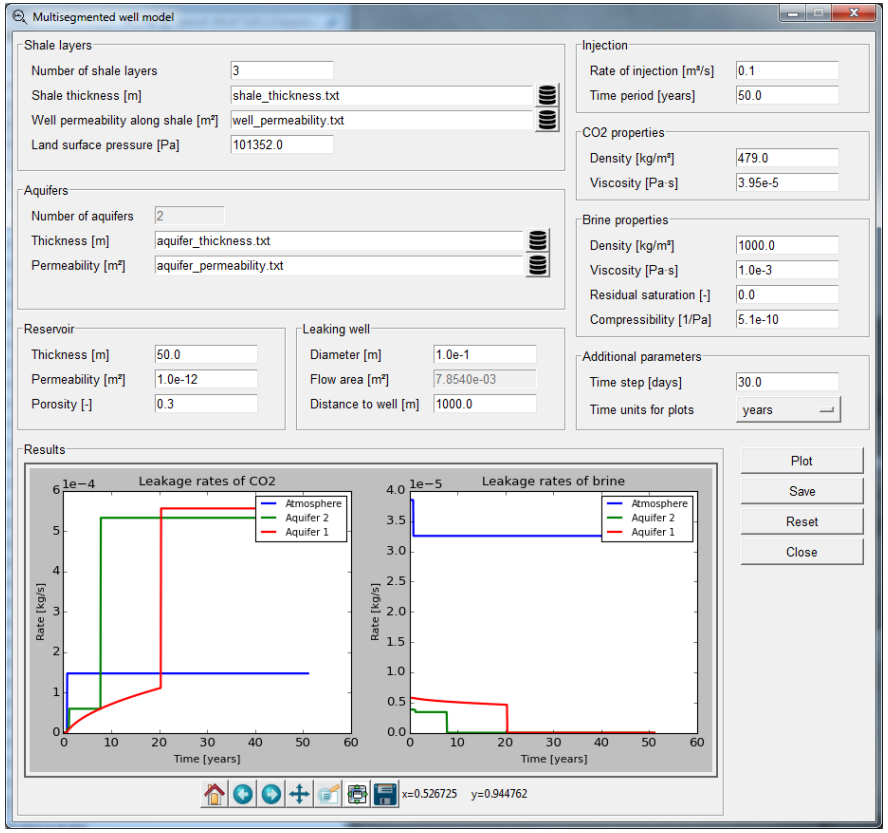
Schedule for NRAP Tool Webinar Series

Date/ Time	Tool	Presenter(s)
October 13 Time: 1pm ET	Integrated Assessment Model–Carbon Storage (NRAP-IAM-CS) (2.5 hours)	Rajesh Pawar
October 19 Time: 1pm ET	Natural Seal ROM (NSealR) (1 hour)	Ernest Lindner
October 26 Time: 1pm ET	Reservoir Evaluation and Visualization (REV) Tool (1 hour)	Seth King
November 2 Time: 1pm ET	Well Leakage Analysis Tool (WLAT) (1.5 hour)	Nicolas Huerta
November 9 Time: 1pm ET	Aquifer Impact Model (AIM) (1 hour)	Diana Bacon
November 16 Time: 1pm ET	Design for Risk Evaluation and Monitoring (DREAM) (1 hour)	Catherine Ruprecht
November 30 Time: 1pm ET	Short Term Seismic Forecasting (STSF) (1 hour)	Josh White, Corinne Bachman
December 7 Time: 1pm ET	TBD	

Check for updates at www.edx.netl.doe.gov/nrap

II. WLAT Overview and Background

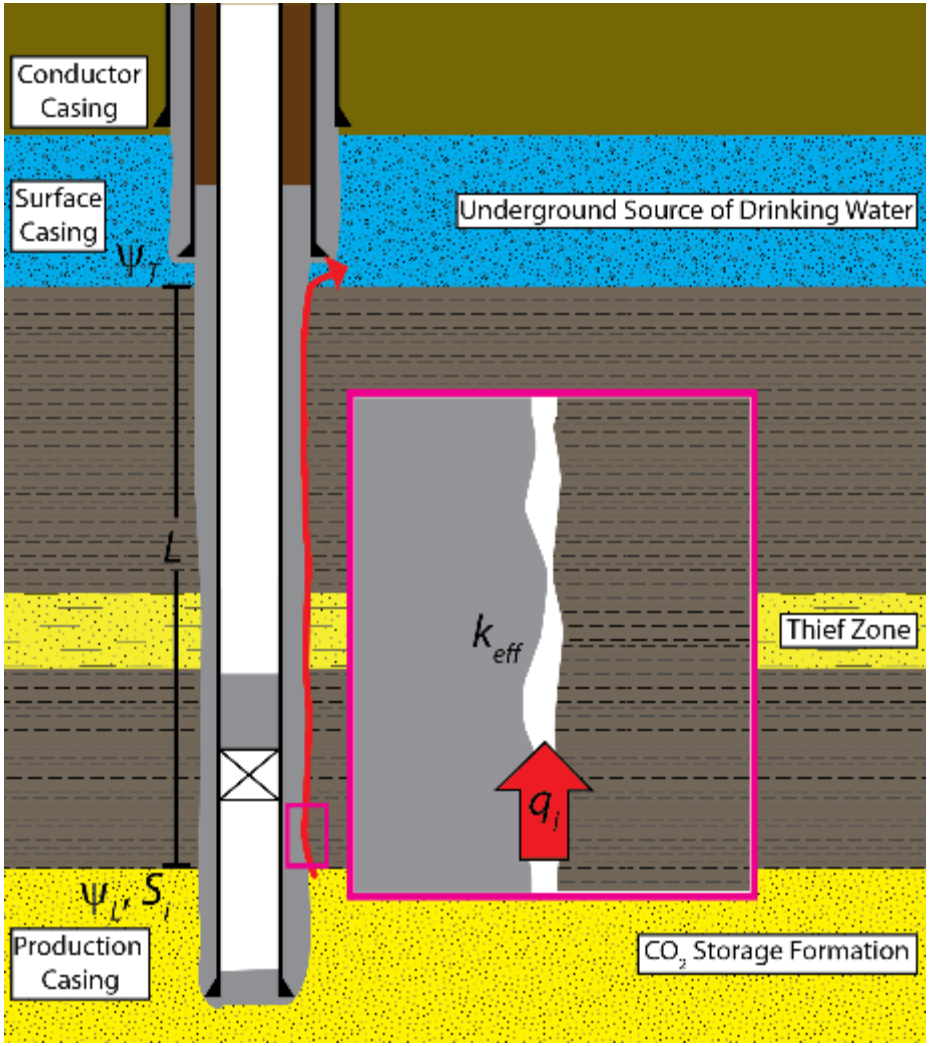
The Well Leakage Analysis Tool (WLAT) is a collection of models that describe various types of potential well leakage.



What can it be used for?

- Understand how an individual well might leak over time
- Compare leakage models
- Test the behavior of the well leakage models in the NRAP-IAM-CS
- Provide a means to test how individual model parameters might affect leak rate
- GUI and Source Code versions available

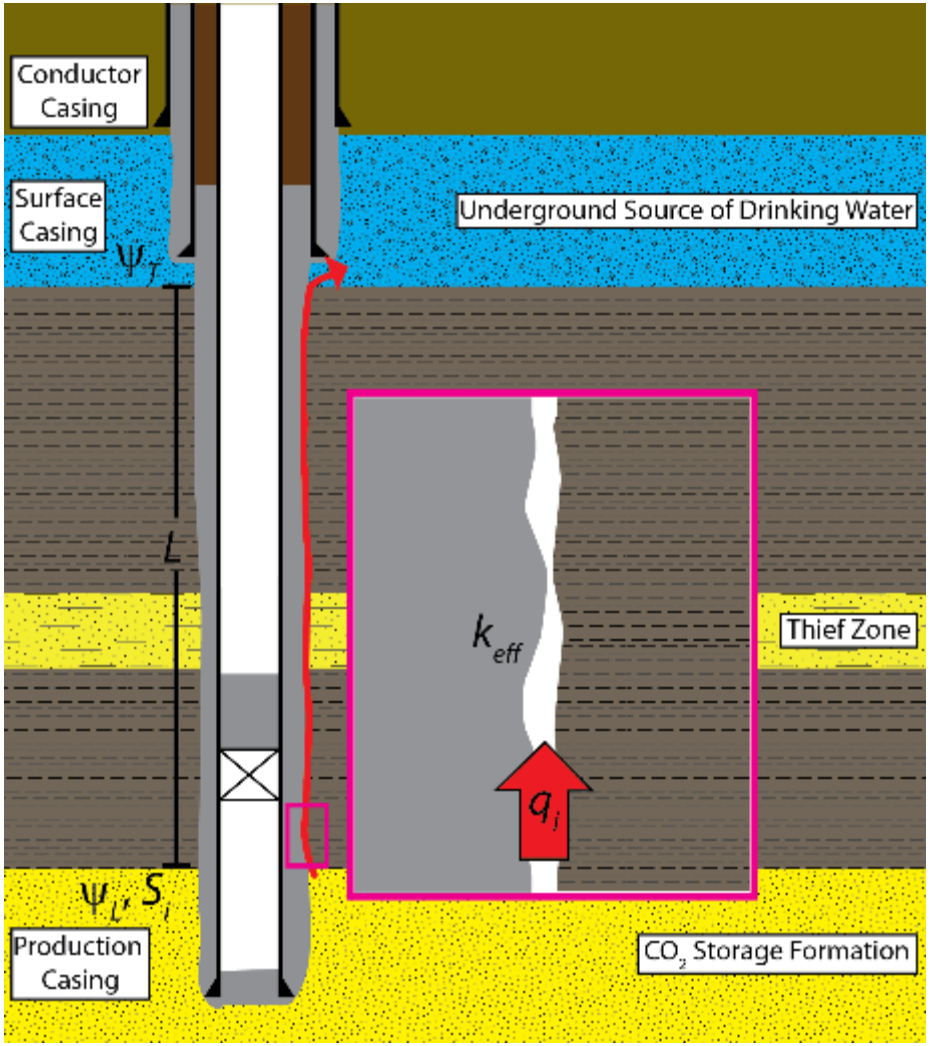
II. Component models in the WLAT



Current version has four well leakage models:

1. **Cemented wellbore model**
   - Treats multiphase flow of CO_2 and brine up a cemented well
   - Can deal with leakage to atmosphere, aquifer, and thief zone
   - Currently incorporated into NRAP-IAM
2. **Multisegmented wellbore model**
   - Uses model developed by Princeton University
   - Treats multiphase flow of CO_2 and brine up a cemented well
   - Can deal with leakage to atmosphere, aquifer, and thief zone(s)
   - Can simulate simple injection and transport to leaky well
3. **Open wellbore model**
   - Treats the flow of CO_2 up an open well
   - Currently incorporated into NRAP-IAM
4. **Brine leakage model**
   - Treats the leakage of CO_2 saturated brine with geochemical effects

III. Input data



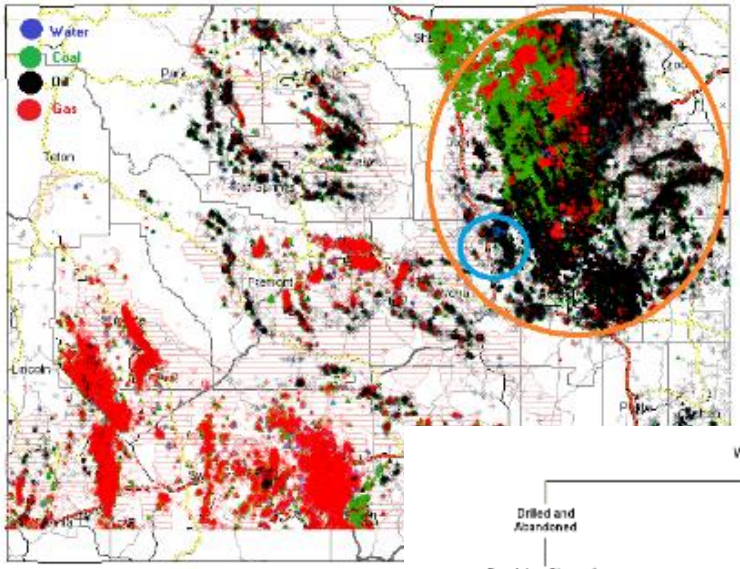
Each model has specific data input needs, but they generally all need:

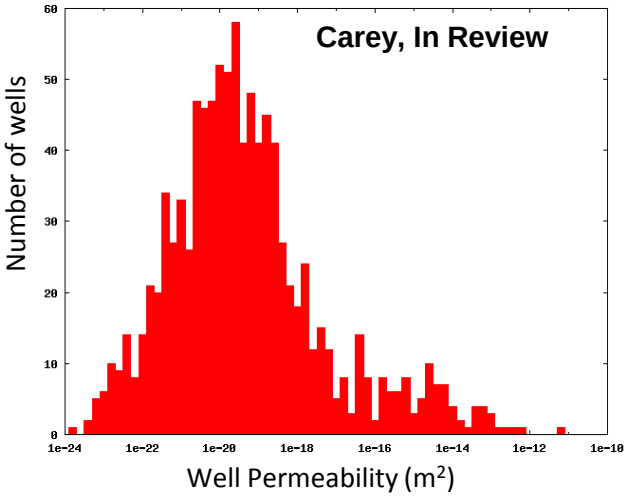
- **Well geometry**
  - Casing data, cement length, annular areas, subsurface formation locations
- **Equivalent permeability**
- **Pressure and saturation at the leak source over time**
- **Timescale of interest**

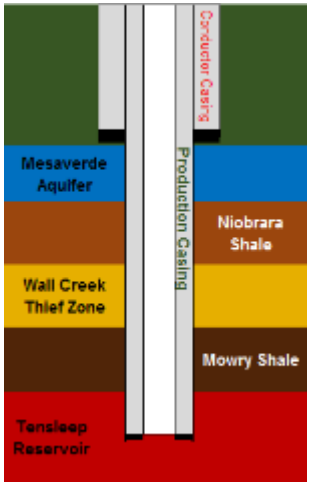
Data can come from:

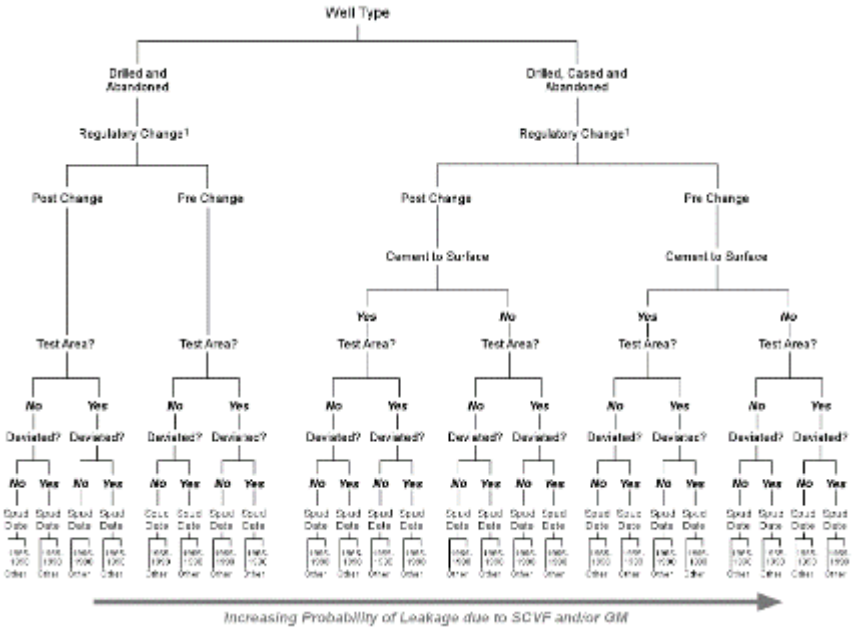
- **Regulatory or industry databases**
- **Published literature**
- **Numerical simulations**

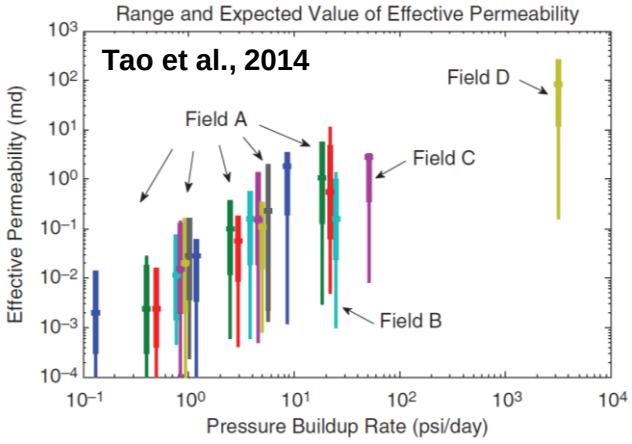
III. Some input data examples







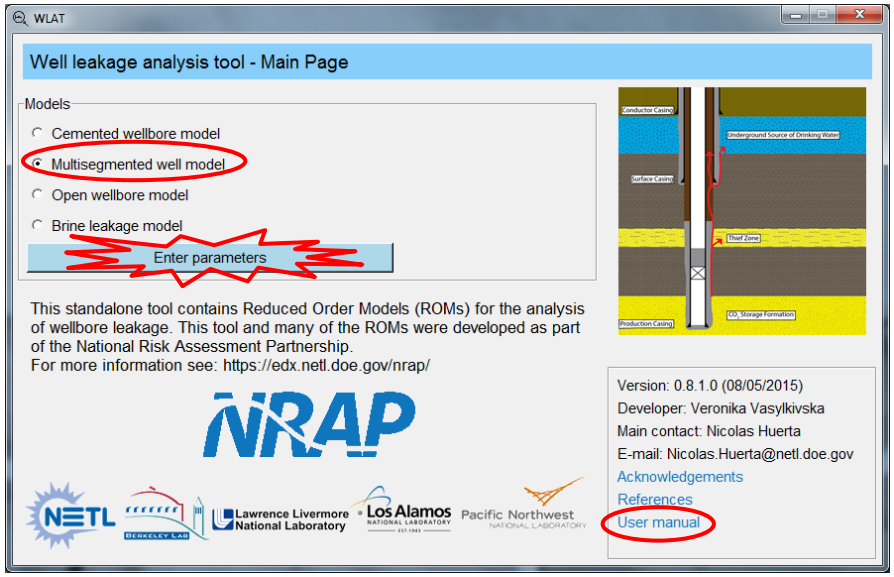


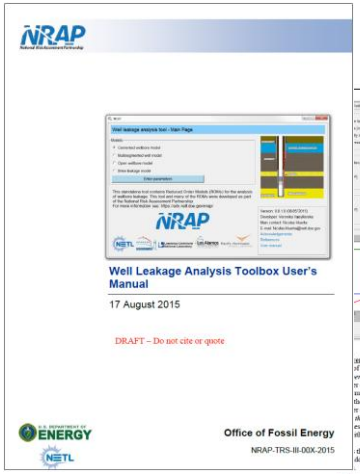


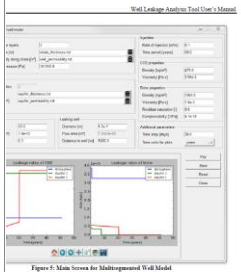
http://wogcc.state.wy.us/

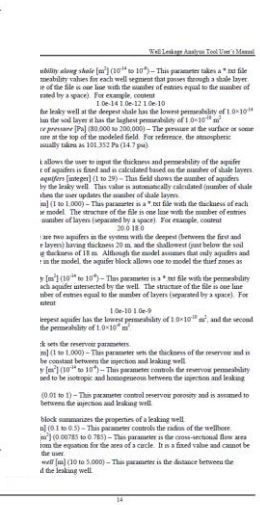
Watson and Bachu, 2009

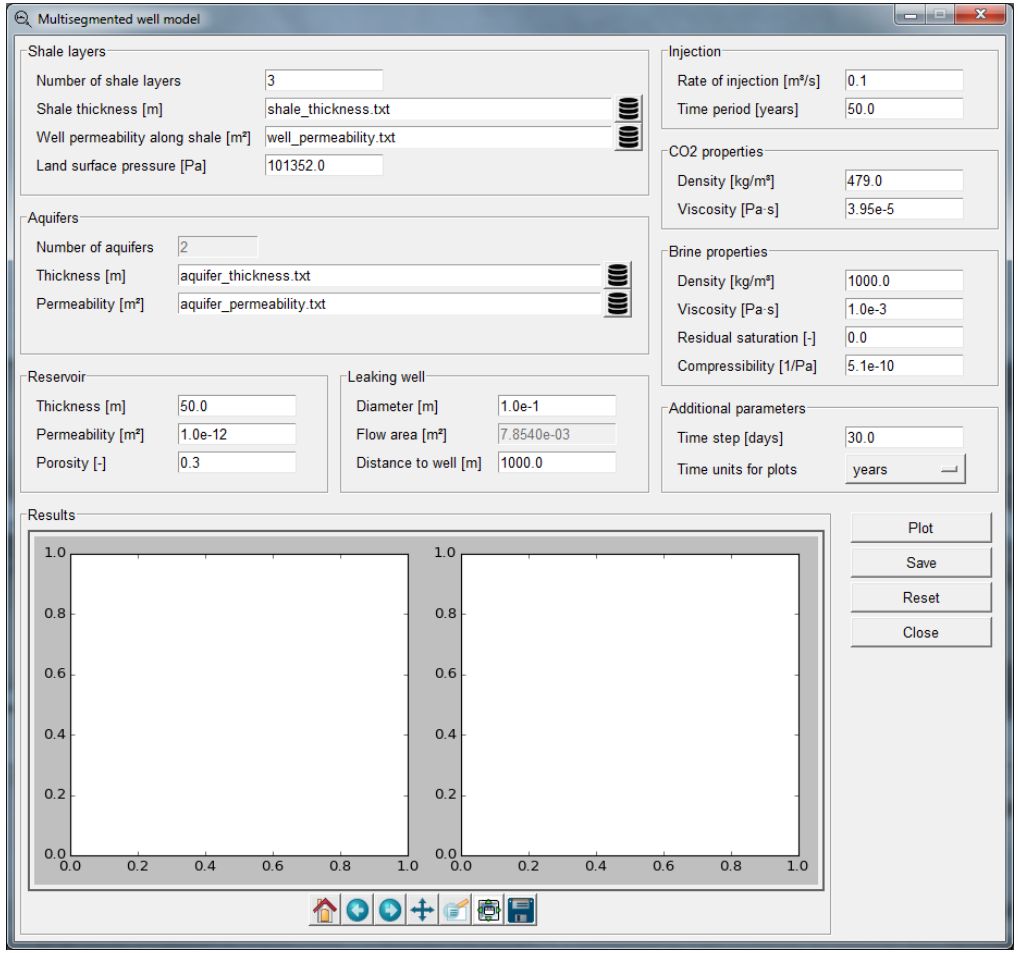
IV. Simple data run with Multisegmented well model



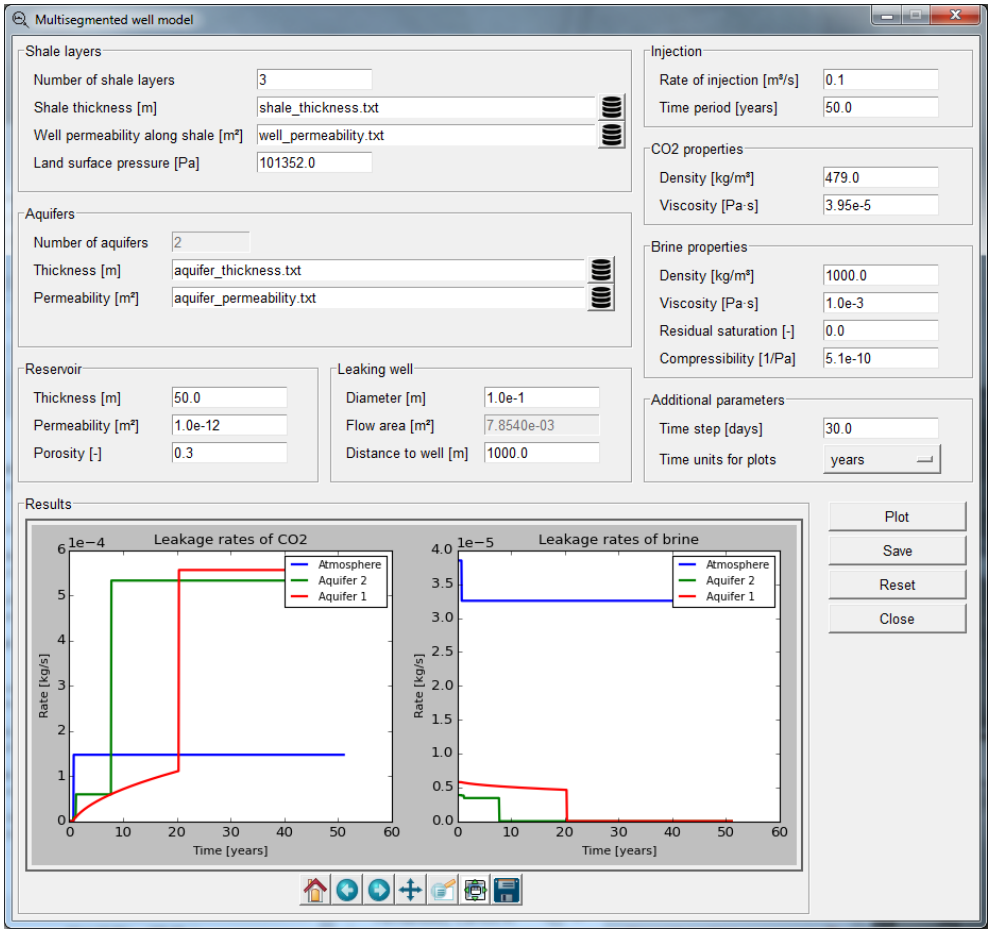








IV. Multisegmented well model - GUI



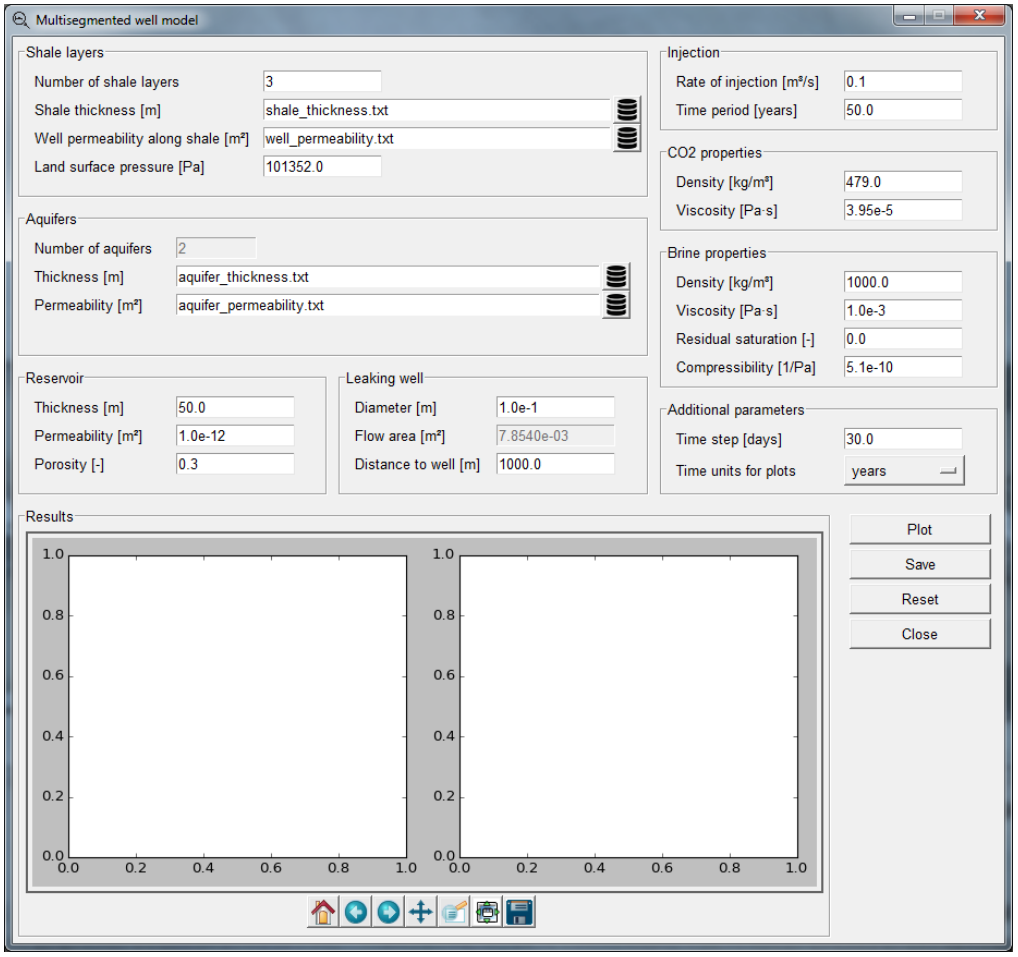
Inputs

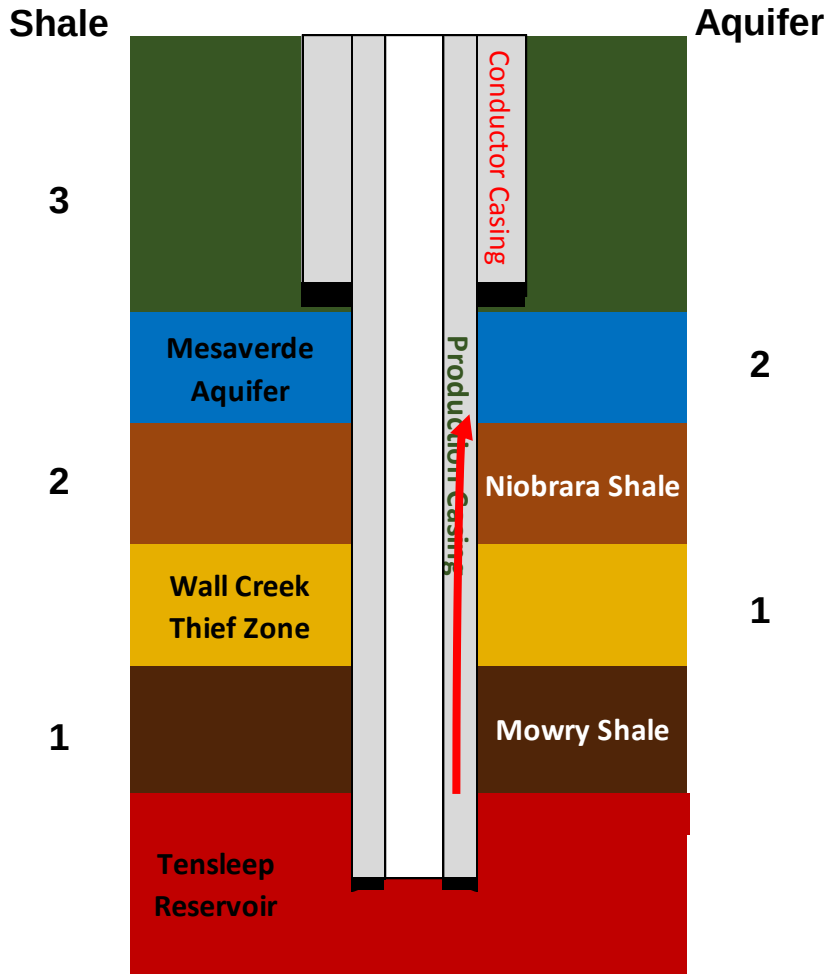
- Scalar values typed into GUI
- Array values loaded via *.txt file

Outputs

- Plotted up on GUI
- Can be manipulated
- Figure can be saved as image or pdf
- Pressure, Temperature, Saturation histories are saved with default names
- Data can be exported as a bulk *.txt file

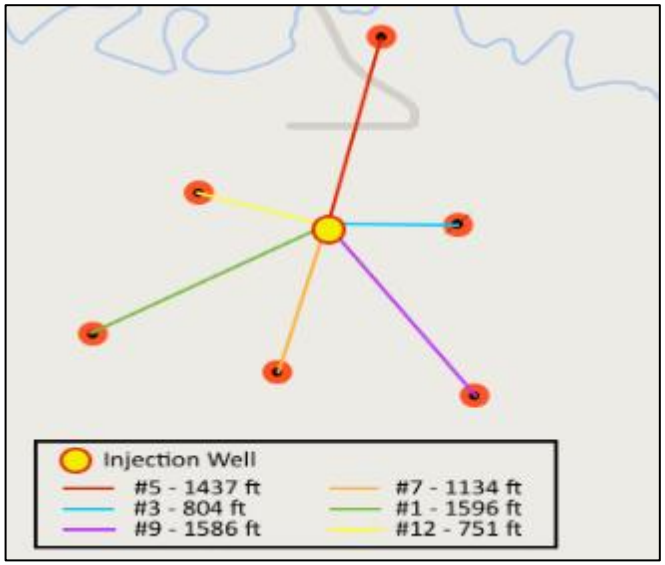
IV. Multisegmented well model - Inputs

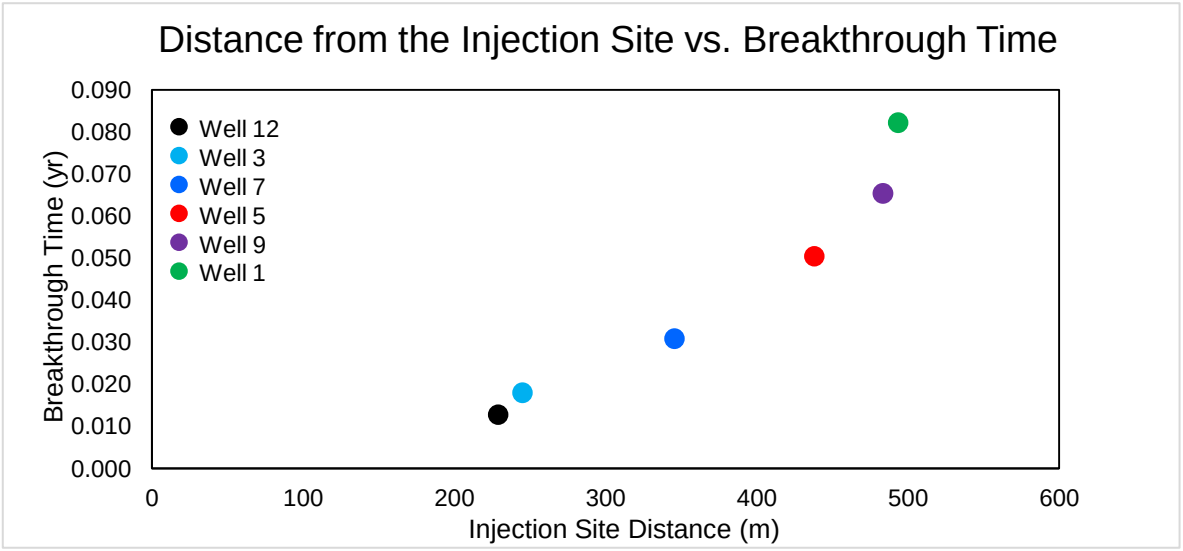




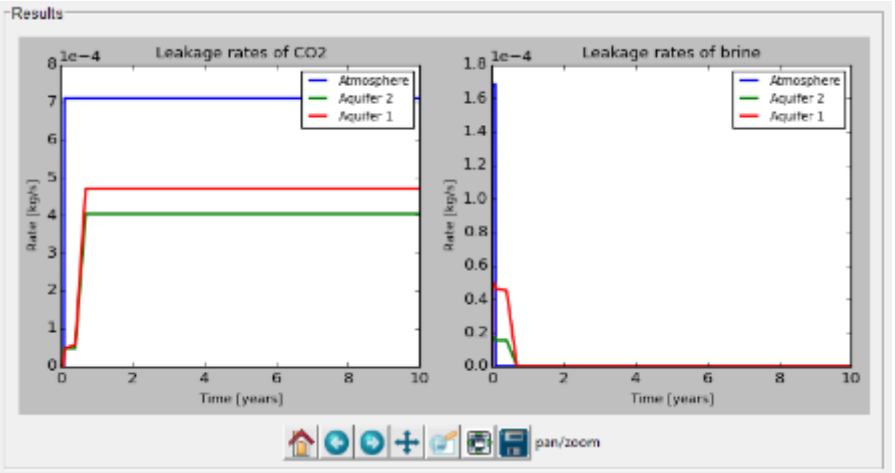
*Hypothetical scenario for demonstration purpose only

Ex. 1: Testing individual parameters





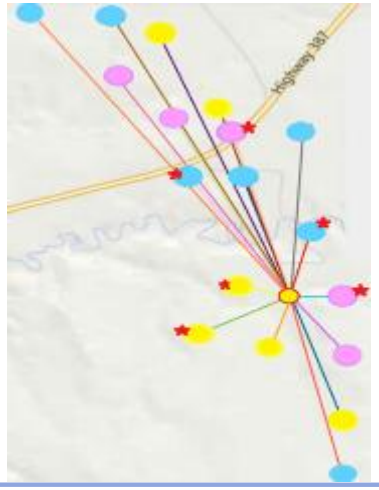
- Using multisegmented well model
- Looking at breakthrough time of CO_2 into Aquifer 1 (Wall Creek)
- Scales as we would expect
- Specifics of the well do have an effect on breakthrough time (annular area, lengths, etc.)

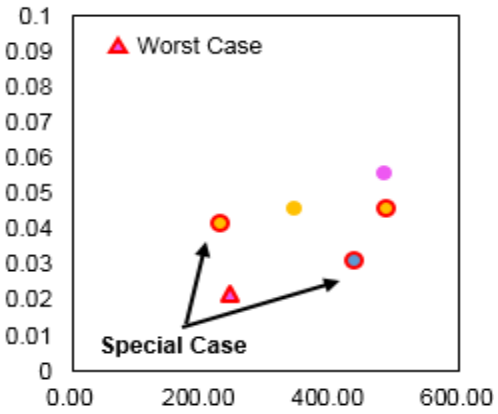


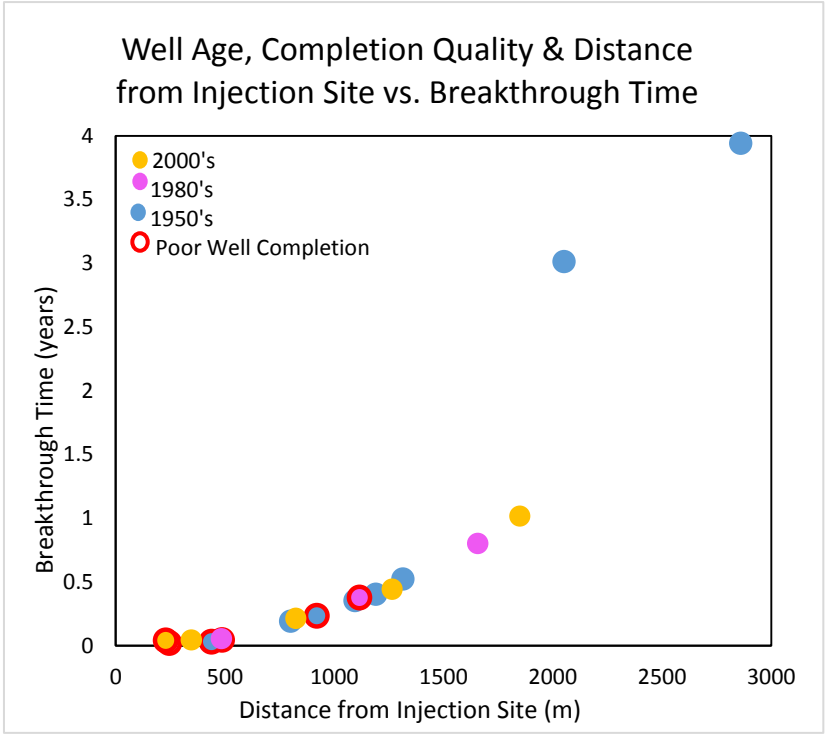
Ex. 2: Adding in risk components

- Relationship between well age, completion type, and cement permeability
- Distance has the greatest impact on breakthrough time
- Well age trumps when similar distances

➢ Importance of permeability in **Well 5**



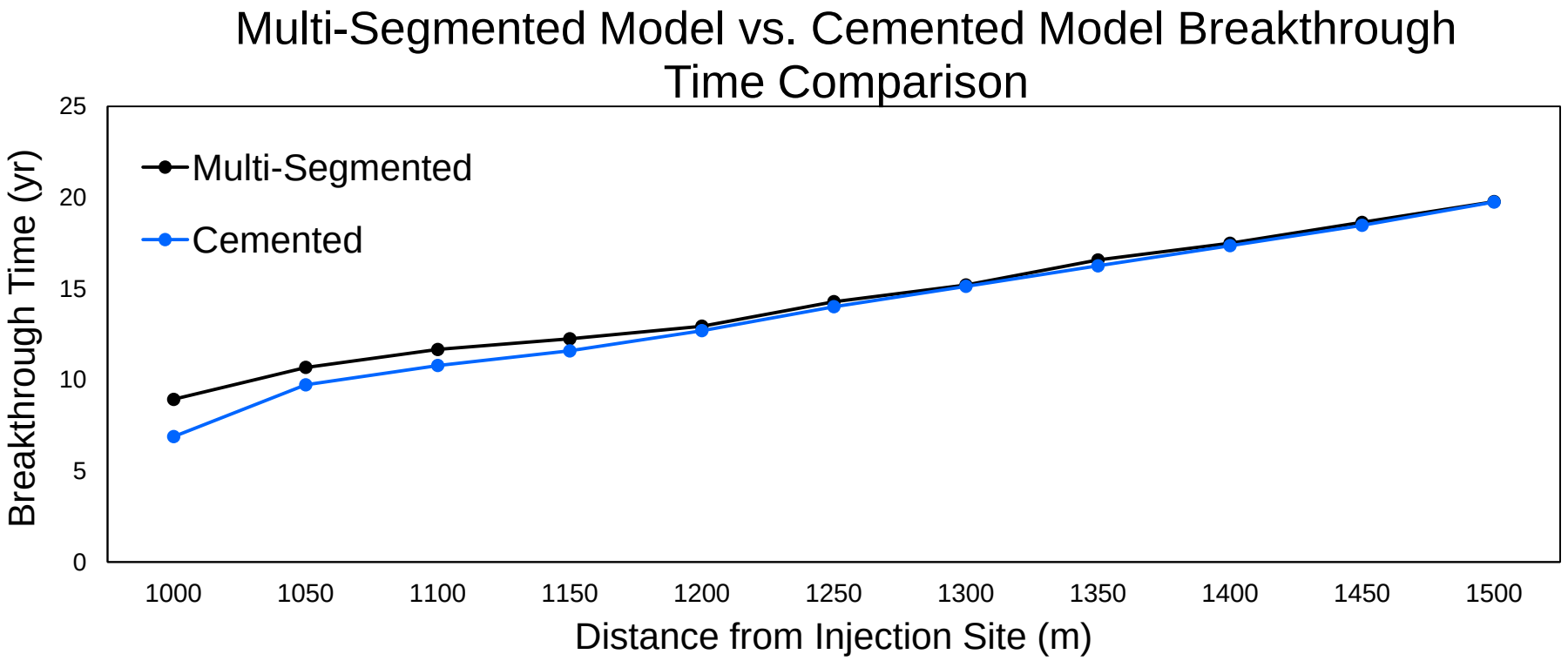




Permeability Values (m^2):

	2000	1980	1950
Good Well Completion	9.869×10^{-17}	9.869×10^{-14}	9.689×10^{-13}
Poor Well Completion	9.689×10^{-15}	4.935×10^{-13}	4.935×10^{-12}

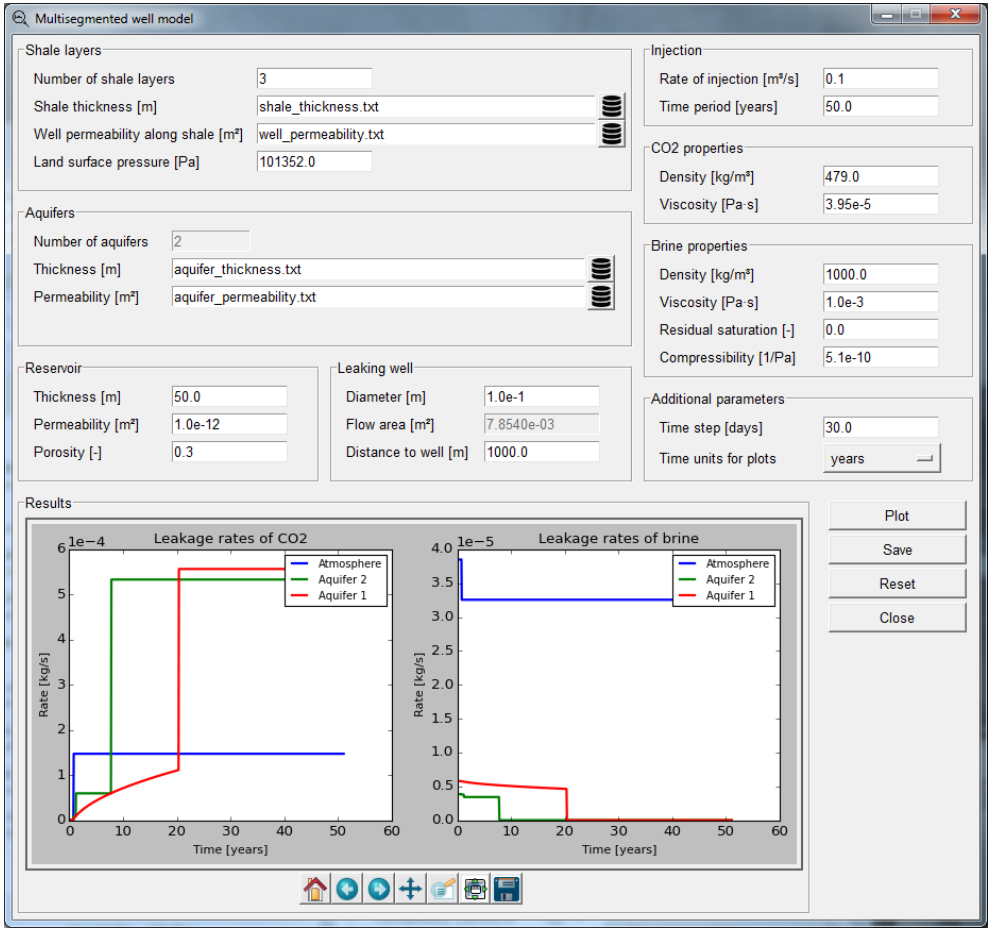
Ex. 4: Model comparison

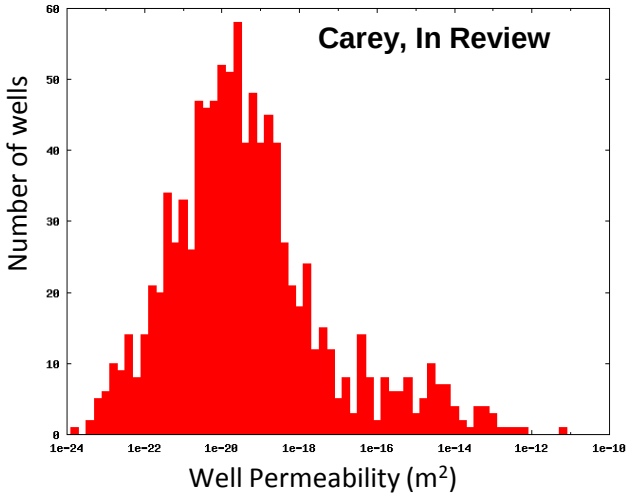


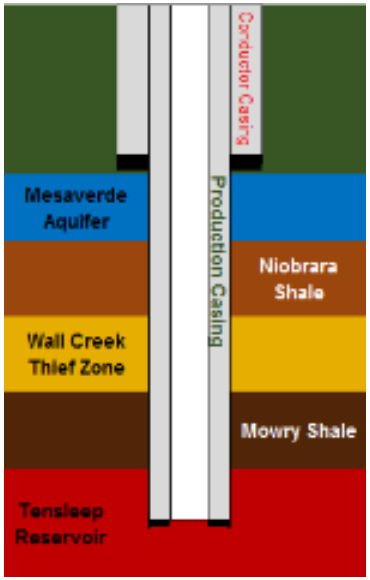
QA/QC and Future Work

- Currently being tested versus high-resolution simulators.
- Case study being developed that can be used as tutorials or work flow example for others.
- Current models will be expanded to allow for more complex subsurface geometry.
- Future models in development to capture effect of geomechanics and geochemistry on long-term leakage.

Questions and Open Discussions

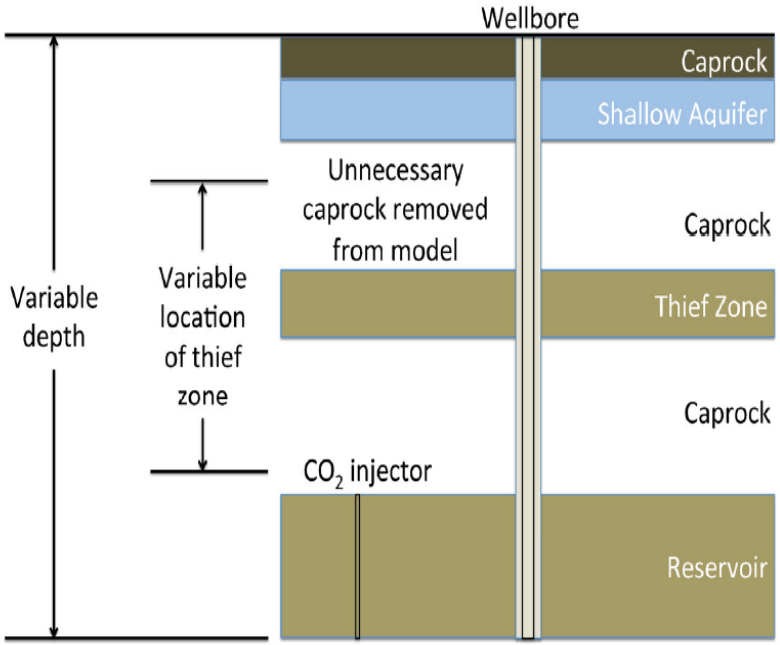




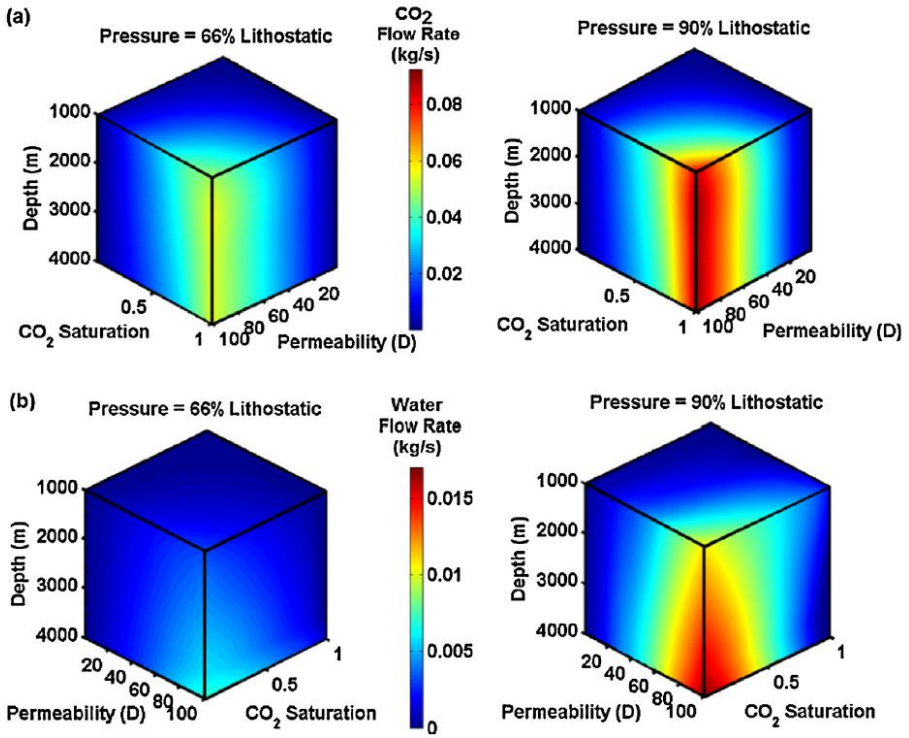


Backup slides

Model 1. Cemented well model



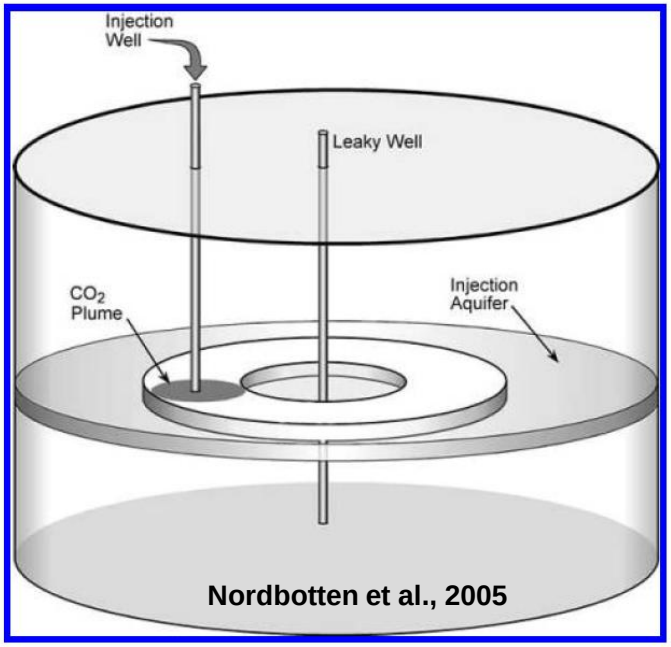
Harp et al., 2014



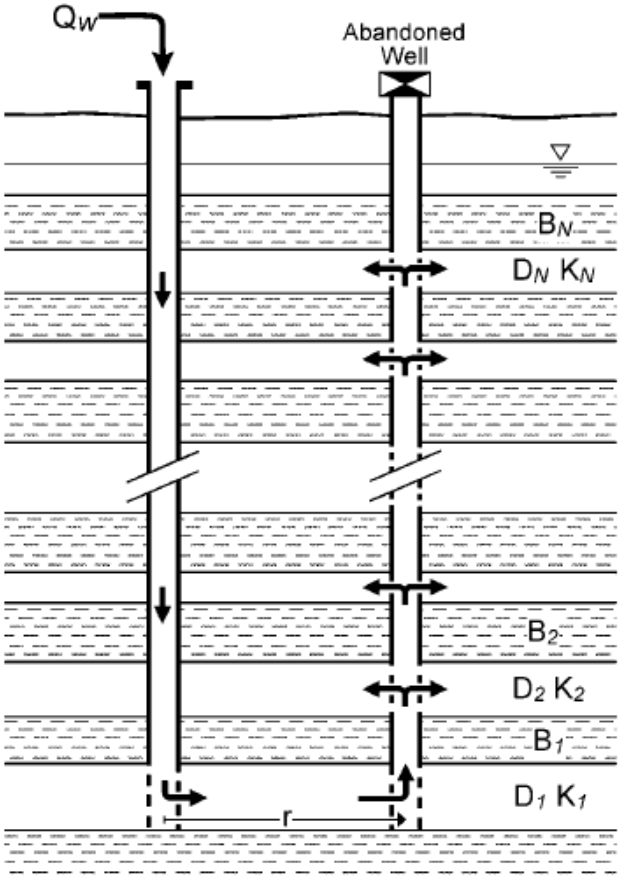
Jordan et al., 2015

- Developed at LANL as part of NRAP
- Treats multiphase flow of CO_2 and brine up a cemented well
- Built from many numerical simulations (FEHM) that are fitted with a response surface to develop polynomials to describe behavior (MARS).
- Can deal with leakage to atmosphere, aquifer, and thief zone
- Currently incorporated into NRAP-IAM

Model 2. Multisegmented well model



Nordbotten et al., 2005



Nordbotten et al., 2004

- Built from models developed by Princeton University
- Treats multiphase flow of CO_2 and brine up a cemented well
- Can deal with leakage to atmosphere, aquifer, and thief zone(s)
- Can simulate simple injection and transport to leaky well

Model 3: Open well model

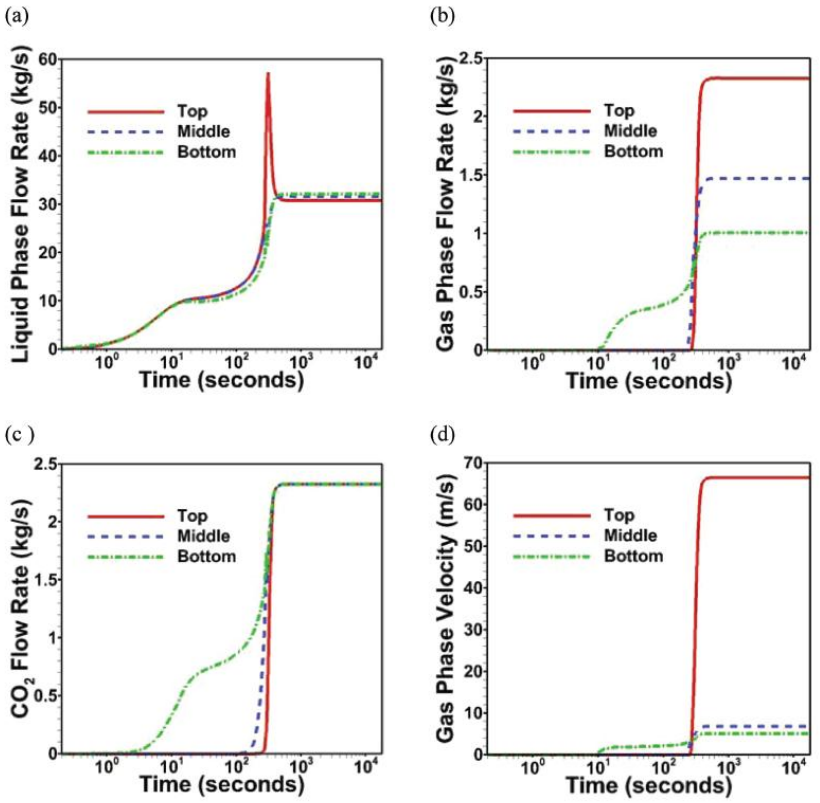


Figure 1. Case 1: Flow rates and velocities of liquid (H_2O-rich phase), gas (CO_2-rich phase), and CO_2 (component) at three levels in the well (bottom, middle, and top).

- Developed at LBNL as part of NRAP
  - Pan et al. (2009, 2011a, 2011b, 2011c)
- Treats the flow of CO_2 up an open well
- Uses Drift-Flux approach
- Currently incorporated into NRAP-IAM
- Can download full version from LBNL as T2Well/ECO2N
  - This version treats injection well, reservoir, and leaky open well

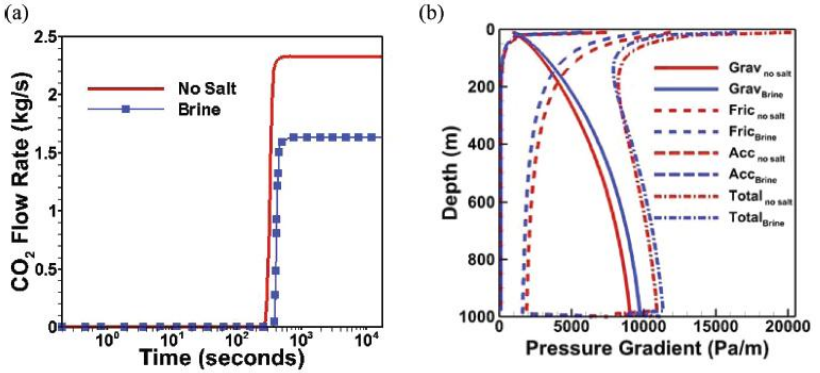
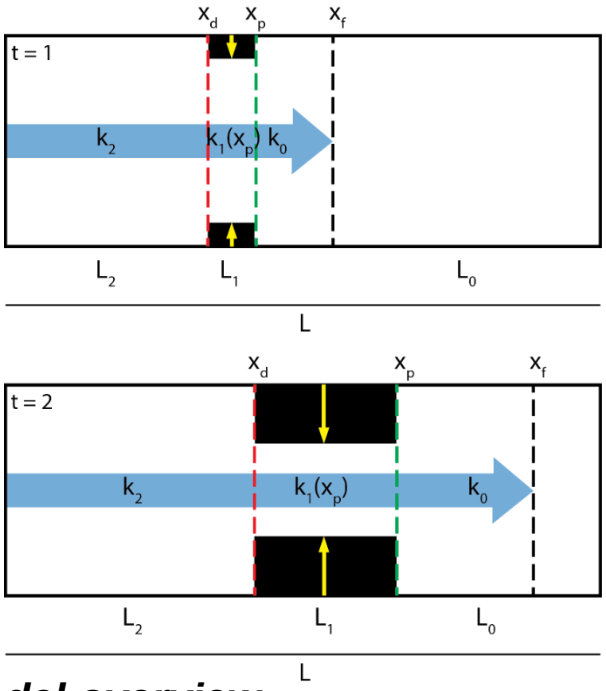
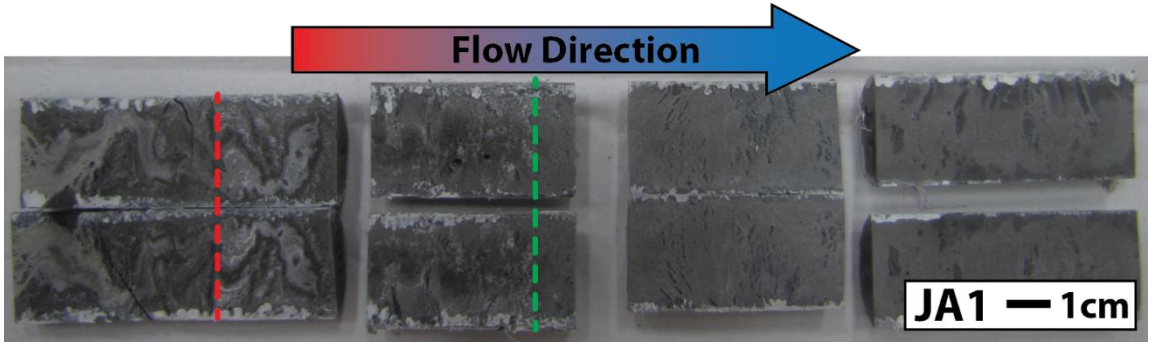
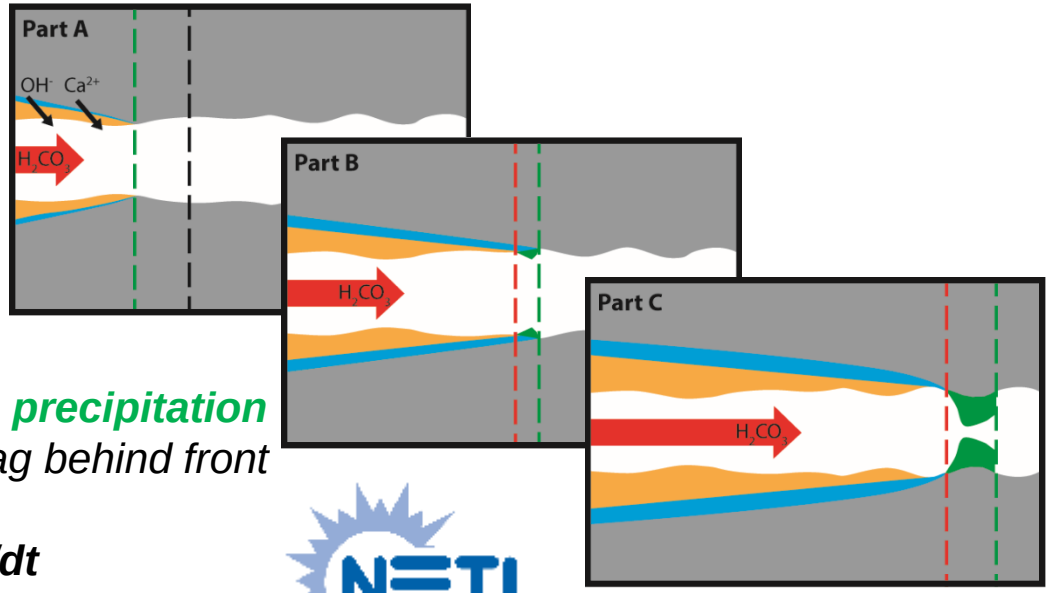


Figure 3. Case 1: The effect of brine on CO_2 (component) leakage rate through the wellhead (a) and the pressure gradients along the wellbore at 36000 s (b). Mass fraction of salt in the brine is 0.12.

Model 4. Brine leakage model







Model overview

- *Darcy's equation for flow in series*
- *As **fluid front** (x_f) moves through core the **precipitation front** (x_p) and **dissolution front** (x_d) will lag behind front but grow at constant rates (α and β)*
- *Solve Darcy's equation such that: **$q = dx_f/dt$***
- *x_f related volume of fluid leaked*
- *Permeability of precipitation zone (k_1) evolves with x_p*